

**Title of the Invention**

**PHOTOMASK AND PATTERN FORMING  
METHOD EMPLOYING THE SAME**

# BACKGROUND AND SUMMARY OF THE INVENTION

The present invention relates to a photomask which is used to manufacture a semiconductor device and the like, and more particularly to a photomask which has been subjected to a processing of shifting a phase of exposure light beams and a pattern forming method employing the same.

Along with an increase of the integration scale for semiconductor devices, sizes of patterns for forming constituent elements of the devices become fine, and size equal to or smaller than the critical resolution of a projection aligner are required. As a method of fulfilling such a request, in JP-B-62-50811 published on October 27, 1987, and corresponding to JP-A-57-62052 (laid open on April 14, 1982) for example, a photomask is employed in which a transparent film for shifting a phase of exposure light beams is provided on one of transparent portions on the opposite sides sandwiching an opaque portion, and thus the resolution of a pattern is exceptionally improved.

In the above-mentioned prior art, a phase shifter needs to be arranged in one of the transparent portions adjacent to each other, and for the arrangement of the phase shifter in the complicated element pattern, high trial and error is

necessarily required. Thus, there is required considerable labor. In addition, since the number of processes of manufacturing a photomask is doubled as compared with the prior art, the reduction in yield and the increase in cost become problems.

Those problems can be settled by employing a semitransparent phase shifting mask in which a semitransparent portion and a transparent portion are provided, and a little quantity of light beams passed through the semitransparent portion is phase-inverted with respect to light beams having passed through the transparent portion. With respect to this point, the description will hereinbelow be given with reference to the accompanying drawings.

FIG. 1A is a cross sectional view showing a structure of an example of a semitransparent phase shifting mask. In the figure, reference numeral 1 designates a transparent substrate, and a reference numeral 2 designates a semitransparent film. A thickness of the semitransparent film 2 is adjusted such that the light beams having passed through the transparent portion 3 is phase-inverted with respect to the light beams having passed through a semitransparent portion 4. The semitransparent film 2 has a

transmittance such that a light beam having passed through the transparent substrate 1 and the semitransparent film 2 has an intensity high enough to cause an interference with a light beam having passed through the transparent substrate 1. The transparent film used in this specification means a film having the above-mentioned transmittance. The light intensity distribution of the projected light beams on a wafer becomes, as shown in FIG. 1B, a sharp light intensity distribution. The reason such a sharp light intensity distribution is obtained is that since the light beams having passed through the transparent portion is phase-inverted with respect to the light beams having passed through the semitransparent portion, the former and the latter cancels each other in a boundary portion of the pattern so that the light intensity becomes approximately zero. In addition, since the intensity of the light beams having passed through the semitransparent portion is adjusted to the intensity equal to or lower than the sensitivity of a photoresist, the intensity of the light beams having passed through the semitransparent portion is not an obstacle to the formation of the pattern. That is, in this method, since the phase inversion effect between the pattern to be transferred and the semitransparent portion therearound

is utilized, there is no need to take, as in the normal phase shifting mask, the arrangement of the phase shifter into consideration. In addition, in the prior art phase shift mask, the two lithography processes are required for the formation of the mask. However, in this method, one lithography process has only to be performed. Thus, it is possible to form the mask very simply.

In this method, the light beams the intensity of which is equal to or lower than the sensitivity of a photoresist, to which the pattern of the mask is to be transferred are made to pass through the semitransparent film so that the light beams which have passed through the semitransparent film is phase-inverted with respect to the light beams which have passed through the transparent portion, and thus, the contrast of the pattern is improved. As a result, it is possible to improve the resolution of an aligner for transferring the mask pattern. The basic principle of the semitransparent phase shifting mask is described in D. C. Flanders et al.: "Spatial period division-A new technique for exposing submicrometer-linewidth periodic and quasi-periodic patterns" J. Vac. Sci. Technol., 16(6), Nov./Dec. pp 1949 to 1952 (1979), U. S.

Patent Nos. 4,360,586 and 4,890,309 and JP-A-4-136854 (laid open on May 11, 1992).

In the lithography process in which the above-mentioned semitransparent phase shifting mask is employed, in the normal exposed area, the good pattern formation can be performed. However, it has been made clear by the investigations made by the present inventors that since in the actual exposure of the wafer, the mask pattern is repeatedly transferred by the step and repeat, the light beams which have leaked from the semitransparent area, which is located outside the periphery of the actual pattern element corresponding to an active region of a substrate, leak out to the adjacent exposed area, and thus this is an obstacle to the good pattern formation.

It is therefore an object of the present invention to provide a photomask by which a good pattern can be obtained even in the case of an exposure, in which a mask pattern is repeatedly transferred by the step and repeat, and a pattern forming method employing the same.

According to one aspect of the present invention, the above-mentioned object can be attained by effectively making a light-shielding or opaque area of a semitransparent phase shift mask which is located outside the periphery of a pattern

element formation area of the semitransparent phase shifting mask.

The light shielding portion in the semitransparent phase shifting mask is formed by processing a semitransparent film to a pattern having a width equal to or lower than the resolution. The reason of adopting such a method is that if a light shielding film is newly formed as the light shielding portion, this will result in an increase of the number of processes of forming the mask. Incidentally, by optimizing the area ratio of the semitransparent portion to the transparent portion, it is possible to further effectively form the light shielding portion.

These and other objects and many of the attendant advantages of the invention will be readily appreciated as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings.

#### BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. 1A and 1B are respectively a cross-sectional view showing a structure of a semitransparent phase shifting mask, and a view showing the light intensity distribution of

projected light beams on a wafer when using the mask shown in FIG. 1A.

FIGS. 2A and 2B are respectively a plan view and a cross sectional view each showing a structure of a photomask according to the present invention.

FIG. 3A is a plan view showing a structure of a light shielding portion of the photomask according to the present invention.

FIG. 3B is a graphical representation showing the relationship between the size of a transparent pattern of the photomask according to the present invention and the intensity of projected exposure light beams.

FIG. 4 is a plan view showing a structure of a mask for forming contact holes of a 64 Mbits-DRAM according to the present invention.

FIGS. 5A and 5B are respectively a plan view showing a structure of a window pattern portion for aligning the position of the mask according to the present invention, and a view showing the light intensity distribution of the projected light beams on the wafer when using the mask shown in FIG. 5A.



FIGS. 6A through 6D are cross sectional views showing steps of a process of manufacturing a semiconductor device according to the present invention.

#### DESCRIPTION OF THE PREFERRED EMBODIMENTS

When both a semitransparent phase shifting pattern and a transparent pattern are arranged with the same size and at a pitch equal to or lower than the critical resolution, a pattern image can be erased. But, in this case, the resulting uniform light intensity does not become zero. This reason is that since there is a difference between the quantity of light beams having passed through the semitransparent phase shifting portion and that of light beams having passed through the transparent portion, the function of cancelling those light beams each other due to the phase inversion effect is not efficiently performed.

Then, when the ratio of the area of the semitransparent phase shifting portion to that of the transparent portion is adjusted in accordance with a set transmittance of the semitransparent phase shifting portion, it is made clear that the light intensity can be zero. By using this pattern for an area of a to-be-exposed water surface, which may be otherwise

undesirably double-exposed by the step and repeat by an aligner, it is possible to prevent the double exposure on the wafer, and a pattern of constituent elements as desired can be formed. Therefore, since the present photomask is made up of only semitransparent phase shifting portions and transparent portions, there is no need to newly form a light shielding film for the formation of the light shielding portion, and thus, the process of forming the photomask can be simplified. Incidentally, the above-mentioned light shielding portion is applicable to the formation of a light shielding portion in a pattern element region of a substrate. In this case, since the ratio of the transmittance of the transparent portion to that of the light shielding portion can be made large, it is possible to increase the tolerance for the variation of the quantity of light beams required for the exposure.

As for the materials used for the formation of the semitransparent phase shifting portion, a lamination film of a semitransparent metal film (made of chromium, titanium or the like) or a silicide film (e.g., a molybdenum silicide film) and a silicon oxide film for the phase shift, or a single layer film such as a metal oxide film (e.g., a chromium oxide film) or metal nitride film (e.g., a chromium nitride film)

may be employed. In the case where a single layer film such as a chromium oxide film or a chromium nitride film is employed, since the refractive index thereof is larger than that of the silicon oxide film, the film can be thinned. As a result, since the influence of the light diffraction can be reduced, this single layer film is suitable for the formation of a fine pattern.

#### Embodiment 1

A first embodiment of the present invention will hereinafter be described in detail. FIGS. 2A and 2B are respectively a plan view and a cross sectional view each showing the appearance of a photomask employed in the present embodiment. In those figures, reference numeral 1 designates a transparent substrate, and reference numeral 5 designates an element pattern portion in which both a semitransparent phase shifting portion and a transparent portion are arranged. Moreover, reference numeral 6 designates a portion acting, on a wafer, as a light shielding portion in which semitransparent phase shifting patterns are arranged at a pitch equal to or smaller than the resolution. Reference numeral 7 designates a masking blade for shielding, on the aligner side, the exposure

light beams. Since the masking blade 7 is poor in the positional accuracy, it is positioned so as to shield the light beams passing through the portion which is located outside the intermediate position of the width of the area 6 acting as the light shielding portion. The details of the area 6 acting as the light shielding portion will hereinbelow be described with reference to FIGS. 3A and 3B. FIG. 3A is a plan view showing a structure of a pattern. In this connection, each transparent pattern portion 10 is formed within a semitransparent phase shifting portion 9. An arrangement pitch 11 of the transparent patterns 10 is determined depending on the resolution characteristics of the projection optical system employed. The arrangement pitch  $P$  is expressed by the following expression:  $P = \alpha \cdot \lambda / NA$ , where  $NA$  represents a numerical aperture of a projection lens,  $\lambda$  represents a wavelength of the exposure light beams, and  $\alpha$  represents a coefficient. In this connection, on the basis of the experiments made by the present inventors, it is desirable that the coefficient  $\alpha$  is set to a value equal to or larger than 0.8. However, the optimal value of  $\alpha$  is not limited thereto or thereby because the optimal value of  $\alpha$  depends on the characteristics of the illuminating system, the pattern

configuration and the like. A width 12 of the transparent pattern 10 influences largely the formation of a dark portion. FIG. 3B shows the intensity of the projected light beams which is obtained on the wafer when changing the width 12 of the transparent pattern 10. Then, the intensity of the projected light beams shows the intensity of the light beams which have passed through the pattern along a line A-B of FIG. 3A. The pitch of the transparent patterns 10 was determined to be  $0.4 \mu\text{m}$  by using  $\alpha = 0.1$  in the expression of the arrangement pitch. With respect to the three kinds of transmittance 9 %, 16 % and 25 % of the semitransparent phase shifting portion, the change in the intensity of the projected light beams were examined by changing the size of the transparent pattern 10. The axis of abscissa of the graph represents the size of the transparent pattern 10. From the graph of FIG. 3B, it can be seen that a minimum value is present in the intensity of the projected light beams depending on the size of the transparent pattern, and this local minimum value is variable depending on the transmittance of the semitransparent phase shifting portion. That is, it can be seen that in accordance with the transmittance of the semitransparent phase shifting portion 9, an optimal transparent pattern size can be found. Denoting

the size ratio of size 12 of the transparent pattern to the size 13 of the semitransparent phase shifting portion 13 by  $\alpha$ , an optimal value thereof for the formation of the dark portion will be expressed by the following expression:  $\alpha = \beta \cdot \sqrt{T}$ , where T represents a transmittance of the semitransparent phase shifting portion, and  $\beta$  represents a coefficient. The allowable intensity of the projected light beams is variable depending on intended purposes. In the case of preventing exposure of a photoresist due to a double exposure, the allowable intensity of the projected light beams may be set to an intensity which is about one-half the intensity of light having passed through the semitransparent phase shifting portion. However, in the case of preventing a double exposure of a dark portion with a fine pattern containing portion, the change in the size of the fine pattern needs to be reduced as much as possible, and thus it is desirable that the allowable intensity of the projected light beams is set to a value equal to or lower than 0.05. The value of  $\beta$  in this case is in the range of about 0.5 to about 2.0. Then, the area 6 of FIG. 2A was formed on the basis of the optimal conditions thus obtained, and by actually using the projection aligner, the pattern element 5 corresponding to the active region was

exposed by the step and repeat. As a result, the good pattern element corresponding to the active region could be formed without occurrence of the pattern destruction and the size shifting even in the area in which the area 6 was double-exposed. As described above, the semitransparent phase shifting portion and the transparent portion were formed with the optimal size combination, whereby the effective dark portion could be formed. Incidentally, although in the present embodiment, the example is shown in which the line transparent pattern is formed in the semitransparent phase shifting area, the present invention is not limited thereto or thereby. That is, for example, there is particularly no problem even in the case of an island-like pattern and other patterns. In such cases, if  $\alpha$  in an expression of  $\alpha = \beta \cdot \sqrt{T}$  is replaced with the area ratio of the area of the transparent pattern to the area of the semitransparent phase shifting portion, the substantially same effects can be obtained. In addition, in the present embodiment, the dark portion which is formed by the combination of the semitransparent phase shifting pattern and the transparent pattern is applied to the prevention of the double exposure. However, the application of the dark portion of the present invention is not limited

thereto or thereby. It is, of course, to be understood that the dark portion is applicable to the necessary portions such as a window pattern for aligning the mask position, a pattern for detecting the wafer position, and a semitransparent phase shifting portion having a large area all of which require a dark portion. Further, the above-mentioned photomask having a dark portion is useful for the pattern formation when manufacturing a semiconductor device.

#### Embodiment 2

A second embodiment of the present invention will hereinafter be described with reference to FIG. 4. FIG. 4 is a plan view showing a structure of a photomask which is used to form contact holes of a 64 Mbits-dynamic random access memory (DRAM). Two DRAM element areas 5 are arranged in a transparent substrate 1. A scribing area 14 is provided between the two pattern element areas 5. In addition, in a peripheral scribing area 15 on two sides perpendicular to each other, a pattern for measuring the accuracy of the mask alignment, a target pattern for the mask alignment, and the like are arranged which becomes necessary for the process of manufacturing a device. In the two sides opposite to the



other sides of the scribing area, a dark area 6 of the present invention is arranged. The step and repeat in the projection aligner is performed at a pitch 16 in the transverse direction and at a pitch 17 in the longitudinal direction. The peripheral portion which is located outside a dotted line 18 as the setting center is mechanically shielded from the light beams by a mechanical light shielding plate of the aligner. In this connection, the dotted line 18 is set at a distance equal to or longer than the positional accuracy of the mechanical light shielding plate from the scribing area such that the mechanical light shielding plate is not shifted to the scribing area by mistake. In addition, the width of the dark portion is set to a value equal to or larger than the positional accuracy of the mechanical light shielding plate, and the dotted line 18 is arranged in the about central portion of the dark portion. Further, at least the three portions of the four corner portions are made dark portions.

As a result of using this photomask in order to manufacture the 64 Mbits-DRAM, the double exposure in the periphery of the chip can be perfectly prevented, and thus the good device can be manufactured. In addition, in the case where the pattern element area 5 is formed by one chip, or the

photomask having the dark portion is applied to devices other than DRAM, the same effects can be obtained.

Further, the description will hereinbelow be given with respect to an example in which the dark portion of the present invention is arranged in the periphery of a window pattern which is used to align the mask position with reference to FIGS. 5A and 5B. FIG. 5A is a plan view showing a structure of the window pattern portion which is used to align the mask position. FIG. 5B shows the distribution of the light intensity on the wafer corresponding to the mask position. As shown in FIG. 5A, a transparent portion 10 which has the size fulfilling the conditions for forming the dark portion of FIG. 3B is formed around a window pattern 19. It can be seen that in the distribution of the light intensity on the wafer along a line A-B of the photomask of FIG. 5A at that time, the light intensity in the periphery of the window pattern is, as shown in FIG. 5B, zero, and thus signals representing the window pattern are obtained in the high signal-to-noise (S/N) ratio and the judgement of the position is performed with accuracy. In such a way, the dark portion of the present invention is applicable to a pattern utilizing light intensity signals each having a high S/N ratio from a mask pattern and

other patterns requiring the light shielding portion as well as to the light shielding in the periphery of a device chip.

### Embodiment 3

Hereinbelow, an example will be shown in which a semiconductor device is manufactured according to the present invention. FIGS. 6A through 6D are cross sectional views showing steps of a process of manufacturing a semiconductor device. By using the conventional method, a P type well layer 21, a P type layer 22, a field oxide film 23, a polycrystalline Si/SiO<sub>2</sub> gate 24, a high impurity concentration P type diffusion layer 25, a high impurity concentration N type diffusion layer 26, and the like are formed in an N<sup>-</sup> type Si substrate 20. Next, by using the conventional method, an insulating film 27 made of phosphor silicate glass (PSG) is deposited thereon. Next, a photoresist 28 is applied thereto, and then a hole pattern 29 is formed by using the semitransparent phase shifting mask of the present invention (refer to FIG. 6B). Next, an insulating film 27 is selectively etched by the dry etching technique with the resultant photoresist as an etching mask, thereby to form contact holes 30 (refer to FIG. 6C). Next, by using the

conventional method, a W/TiN electrode wiring 31 is formed, and then an interlayer insulating film 32 is formed. Next, a photoresist is applied thereto, and then by using the conventional method, a hole pattern 33 is formed using the semitransparent phase shifting mask of the present invention. Then, a W plug is plugged in the hole pattern 33 to connect a second level Al wiring 34 thereto (refer to FIG. 6D). In the following passivation process, the conventional method is employed. Incidentally, in the present embodiment, only the main manufacturing processes have been described. In this connection, the same processes as those of the conventional method are employed except that the semitransparent phase shifting mask of the present invention is used in the lithography process of forming the contact hole. By the above-mentioned process, CMOS LSI can be manufactured at a high yield.

As set forth hereinabove, according to the present invention, by forming the semitransparent phase shifting portion and the transparent portion with the optimal size combination, even if a light-shielding film is not newly formed, the effective dark portion can be formed. In addition, without increasing in the number of processes of

forming the mask, the semitransparent phase shifting mask which is useful in practical use can be produced. Further, as a result of manufacturing the semiconductor device by using the photomask of the present invention, it is possible to form the pattern in which the effects inherent in the semitransparent phase shifting mask are sufficiently utilized, without any problem in the double exposure portion, and also it is possible to realize the reduction of the device area.

It is further understood by those skilled in the art that the foregoing description is a preferred embodiment of the disclosed device and that various changes and modifications may be made in the invention without departing from the spirit and scope thereof.